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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

This Issue

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ABRASIVES AND WEAR

TEXACO
REG. T. M.

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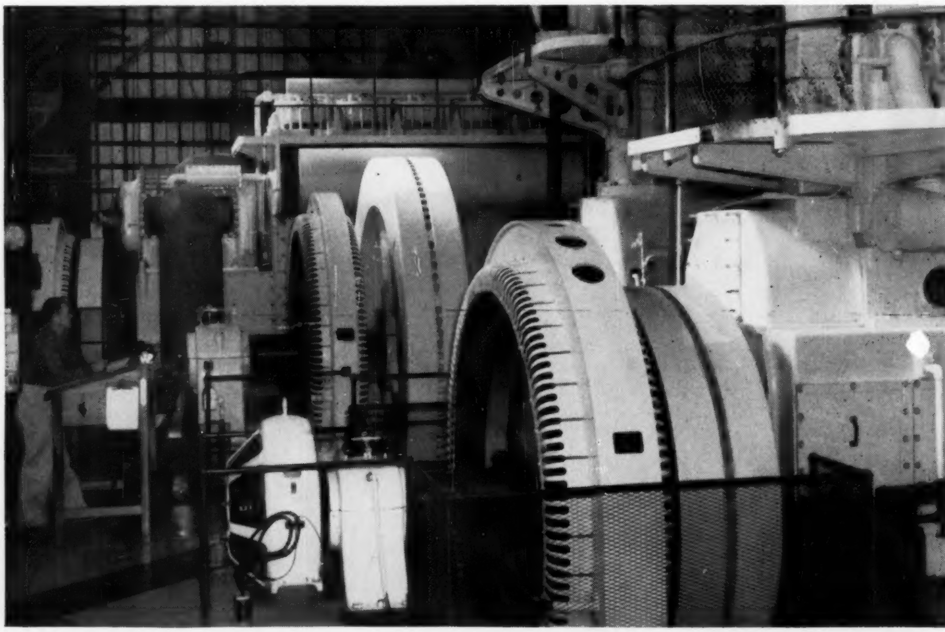

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ABRASIVES AND WEAR

SAND or cinders are spread on icy sidewalks to provide pedestrians with a firm footing. Sand directed under the drive wheels increases the traction of a railroad locomotive; however, while doing so, the tires and rails become worn, especially when slippage occurs.

Sand and certain other earthy minerals assist in controlling friction in many other applications, but in bearings and between other lubricated surfaces, grit is anathema.

Sometimes a trace of dust can cause a bearing failure. Many other less critical applications, however, can ingest fairly large volumes of grit with little or no immediate trouble. In fact, in some industrial applications as well as on older farm vehicles, the grease-lubricated wheels are today as exposed to the dusts of the fields as were the wheels of the Pharaoh's chariots over 3500 years ago. Whereas the charioteers could use but a mutton tallow to lubricate their hubs, modern wheels have scientifically compounded axle greases. Nevertheless, the final outcome may be the same; parts wear out too soon. The lack of proper attention to functional details can result in abrasive wear which shortens the lives of many bearing installations.

Abrasives can enter a lubricating system during parts assembly and during service operation. Precautions must be taken under *both* conditions to prevent such contamination and thereby minimize wear and early parts failures.

It was long known that unctuous materials — animal and vegetable oils and fats, and later petroleum — had the ability to reduce friction between moving parts. The theory of hydrodynamic lubrication indicates that under certain conditions a fluid lubricating film could completely support the journal with no metal-to-metal contact between the bearing and journal. Under such conditions, wear should be reduced to a very low value; but, generally, wear will not be entirely eliminated unless special precautions are taken. That persisting form of damage can be attributed to abrasive solids entrained in the lubricant.

Grit, sand and abrasives are not compatible with surfaces in relative motion. Friction is increased and the sliding surfaces become worn. Too often, however, one fails to recognize how extreme may be the damage from supposedly insignificant amounts of abrasive material, especially in bearing clearances that are not inherently capable of accommodating relatively large particles in the oil stream.

BEARING DESIGN

A machine designer, in laying out a new mechan-

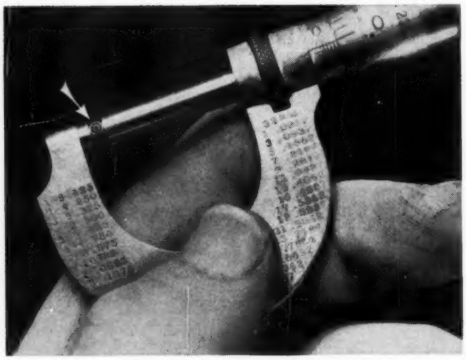


Figure 1 — Miniature ball bearings such as this instrument bearing require lubricants that are absolutely clean of abrasive contaminants.

ical device incorporating bearings and other moving parts, calculates the journal or plain bearings to carry their loads upon a complete hydrodynamic film. Actual operation, however, is frequently far from that ideal; thin film conditions often exist and early bearing failure can occur unexpectedly. Under full fluid conditions of lubrication, the composition of the bearing surface can be practically any metal, including tool steel, brass, zinc, aluminum, bronze, etc., and many non-metals such as plastic, glass or wood.

In the smallest sizes of ball bearings, for example, minimum friction is absolutely necessary. Figure 1 shows a ball bearing (arrow) from an aircraft navigational instrument which is so critical that one grain of sand in the lubricant can render it useless. In certain pieces of electronic equipment such as tape recorders, a trace of dust will raise the noise level of the bearing beyond the limit of tolerance. More commonly, the effects of abrasives are noted in high speed plain or journal bearings which are sensitive to abrasives because of their very design requirements.

In practical circumstances where continuous hydrodynamic conditions cannot exist, the designer is forced to choose bearing alloys which, while carrying the journal load in an acceptable manner, must be so constructed as to mitigate any hazards arising from a possible bearing failure. Compromise is necessary in bearing design.[1]

In journal bearing applications, compromise forces bearing designers to incorporate such contradictory characteristics as high strength to support the shaft without crushing, but sufficient plasticity to conform to irregular and misaligned shafts, and sufficient embeddability to accommodate foreign particles. The bearing must have good fatigue strength, yet provide a slippery surface action under conditions of thin film or marginal lubrication.

Large industrial bearings which can be formulated in a most conservative manner attain some of the afore-mentioned design criteria with relatively thick babbitt bearings. By making the bearings large, unit loads will be low and, accordingly, demands upon their strength characteristics and fatigue resistance are not excessive. Thick babbitt surfaces are ideal for accommodating abrasive conditions; the soft surface is highly embeddable. Granular material or chips of quite considerable size can be pocketed within the bearing surface with no obvious damage to either the bearing or the shaft. Figure 2 shows the cross-section of a bronze bushing in which two small particles of hardened steel are embedded in a leaded bronze matrix. The presence of lead increases the deformability of bronze. Note how the bronze has been distorted by the impression of the granules and how the tops of the granules are almost flush with the bearing surfaces.

In heavier-duty-bearing applications such as in internal combustion engines, design loads and temperatures have become too great to be supported successfully by thick layers of babbitt. Such a bearing frequently fails by fatigue cracking brought forth by greater intensities of impulse loadings and by higher temperatures which weaken the metal, thereby reducing its endurance limit.

To circumvent these deficiencies, two different design trends have taken place in heavy-duty bearings. They now either: (1), have an extremely thin layer of babbitt alloy coated directly onto a steel supporting shell, commonly used in the automotive industry; or (2), are multi-layer bearings, each component of which has some unique attribute contributing to overall good bearing performance.

Figure 2 — Hard steel particles about 0.005 in. diameter embedded in the surface of a leaded bronze bushing. Magnification 100X.

[1]For a more complete treatment see Lubrication, October 1954, "Industrial Bearing Lubrication."

These would include steel shells covered with lead on aluminum, lead on copper-lead, lead on bronze and lead on silver. In most instances, the lead surface layer contains a small amount of tin (up to 10 per cent) or indium (up to 5 per cent) to improve hardness and resistance to corrosion from organic acidity. This acidity arises from products of incomplete fuel combustion and from oxidation of uninhibited lubricating oils. Table I is a listing of these multi-component bearings rated in order of decreasing embeddability or deformability.

The aircraft industry, in constantly striving for maximum horsepower in a limited space, has created bearing loads in excess of 10,000 pounds per square inch for which only the lead-on-silver design has proven acceptable. In this, the silver is electrodeposited to a thickness of 10-20 thousandths inch. Over this is the lead layer 0.5-1.0 thousandth thick into which the indium is diffused, thereby creating a lead-indium alloy. This aircraft bearing has one thing in common with all the other heavy-duty bearings: a thin lead (alloy) surface layer covering steel or another bearing metal considerably harder than lead.

The lead layer must be thin to carry the load; a thick layer would plastically squeeze out or fatigue. That very thinness, however, creates a severe problem from the standpoint of resistance to abrasion. Embeddability is limited; the lead layer can accommodate only the smaller particles within itself. Large particles are held either above the normal bearing surface in a manner that can scratch and score the shaft or, under high journal pressures, be forced into the silver or other intermediate layer, distorting that surface as did the granules in Figure 2. Heavy-duty bearings, therefore, are inherently sensitive to solids in the lubricant.

TABLE I

Bearing Materials Listed in Order of Decreasing Embeddability or Deformability

- Pure lead
- Babbitts, lead and tin base
- Cadmium alloys
- Copper lead
- Thin babbitt overlays (less than 0.003")
- Copper lead alloyed with tin or silver
- Aluminum alloys
- Silver and Copper
- Bronzes

BEARING DAMAGE

A lead-flashed copper-lead bearing insert is illustrated in Figure 3 after an extended run on an abrasive-laden oil. The engine which carried this bearing operated a piece of excavating equipment with a damaged air intake filter. It can be seen that the tracks made by the particles flow diagonally outwards from the central oil groove, following the general flow pattern of the oil.

Another example of erosion from dirty oil is shown in the diesel main bearing in Figure 4 where a broad band of damage fans outwards from the oil supply hole. Valleys of erosion such as these continue to extend themselves and, in time, a channel will be cut large enough that it allows a rapid flow of oil from the bearing clearance. This starves the bearing of oil and hastens ultimate failure.

Similar damage can be started by an embedded particle or a score mark which creates a discontinuity in the oil flow. At such a point intensive vibration (cavitation) may be set up which can be strong enough to pluck material from the bearing, leaving a sharp-sided channel in the direction of oil flow. This phenomenon is usually made more severe when the bearing is under high frequency repetitive loading such as occurs in some internal

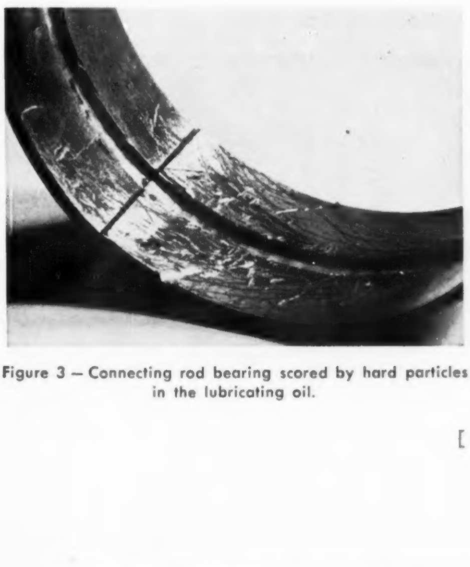


Figure 3 — Connecting rod bearing scored by hard particles in the lubricating oil.

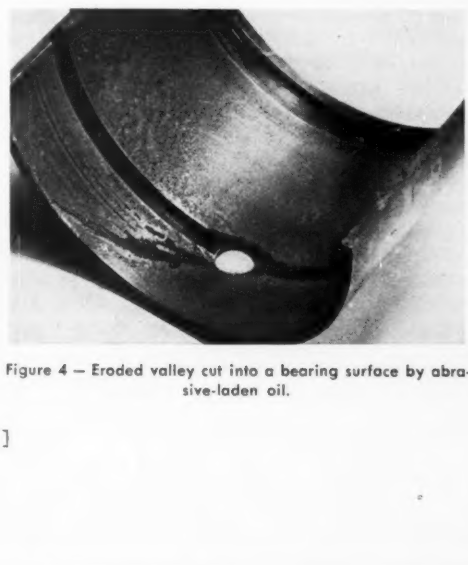


Figure 4 — Eroded valley cut into a bearing surface by abrasive-laden oil.

Figure 5 — Surface of hardened steel journal galled from heavy rubbing on a mild steel bearing shell. Magnification 10X.

combustion engines and in spur gears. The reduction in bearing contact area plus the resultant oil starvation usually lead to eventual bearing failure.

When a moving part is suspected of being worn, a close scrutiny of the translating surfaces often reveals the mechanism of damage and this, in turn, suggests a cure. A decrease in diameter of a journal or pin, an increase in bearing clearance or looseness, a drop in oil pressure all suggest wear; but whether this be from metal-to-metal attrition or to foreign abrasives may not be apparent until the detailed surface in question is examined closely.

In general, metal-to-metal wear[2] may show small areas of incipient welding or galling with a broken-up scored surface. The scoring may produce a ploughed surface in which metal was removed or there may be areas where metal was transferred, moved from one spot and redeposited further on. Figure 5 shows a typical galled steel surface where the smeared metal is very pronounced.

Abrasive wear is distinctively different from metal-to-metal wear in that no metal transfer or galling occurs. The damaged surface will be either scratched or abraded as is shown by the hardened steel pin in Figure 6. This pin was rotating against a bronze bushing of low embeddability; abrasive granules scratched the steel only in their direction of motion. A measure of the roughening is shown in Figure 7 by traces of the surface profiles on the original and damaged zones. These traces were made parallel to the shaft axis and magnify the vertical height of the surface roughness 4,000 times. From these charts it can be determined that the finish of the new pin was 3.5 microinches r.m.s., while the scratched zone had a finish of 32 microinches r.m.s.

When the abrasive granules are very fine, no discrete scratching or grooving may be noticed. Instead the surface smoothness may be altered, a dull matte finish being produced. The latter appearance is more noticeable in ball and roller bearings due to their initially high finish which is easily dulled by any surface change.

ABRASIVE MATERIALS

Certain types of granular solids — gritty minerals — are generally recognized as being potentially abrasive and attempts are made to eliminate them automatically from the lubricating system. Such solids might include beach sand, stone fragments, road dirt, cinders, fly ash, etc. Other materials equally dangerous may gain entry into mechanical systems through lack of awareness on the part of the operator or overhaul mechanic, who may not give proper consideration to the nature of the materials being handled. These might include valve grinding or lapping compounds, often applied in a paste form or in suspension in liquids such as soluble oil; it may represent the dust of a tool-post grinder settling on the unprotected ways of a machine tool.

Other granular materials which may smother an engine at overhaul may be the various grit-blasting substances for cleaning surfaces, particles used for shot-peening, etc. Some of these are mineral in composition, others may be round or irregular steel pellets. Nevertheless, the dregs of such abrasives which are designed especially to cut metal can abrade much more severely than the usual terrestrial dusts unless removed by careful cleaning. Often an incomplete cleaning will remove such materials from outside surfaces but will leave particles trapped in oil passages, blind holes and other hiding places from which the lubricating oil can put them into circulation.

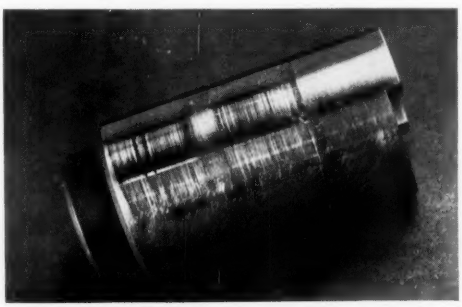


Figure 6 — Hardened steel pin scratched by abrasives trapped in the bearing.

[2] The problem of metal-to-metal contact during thin-film lubrication is discussed in greater detail in the December 1956 issue of "Lubrication" entitled, "Fundamentals of Wear."

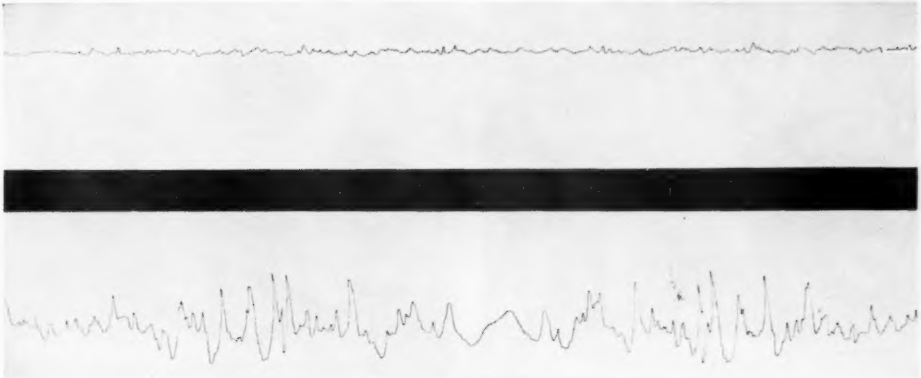


Figure 7 — Traces of surface roughness of scratched pin.
Above: original surface.
Below: scratched surface.

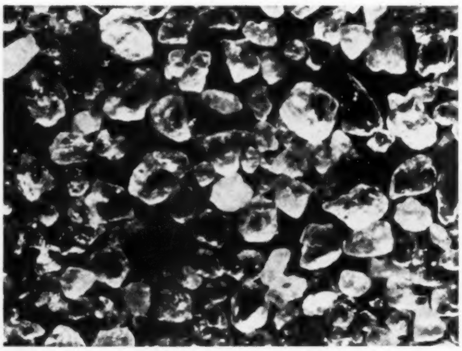
Several of these more-readily available materials are shown in Figure 8. The somewhat rounded nature of common beach sand (Photo A) is typical of granules washed and tumbled by waves and wind which wear away any sharp angles. In contrast to this, the man-made abrasive silicon carbide (Photo B) is highly fragmented, possessing many sharp-cutting jagged angles. The garnet granules (Photo C) are a natural mined product and, being well-rounded, reveal a tumbled existence. Garnet varies somewhat in composition but has a Mohs hardness like quartz in the range of 6.5 to 7.5. The steel pellets (D) were obtained from an air-blasting parts cleaner; these particles are file hard. The grinding chips (E) were picked up by a magnet located close to a high speed steel tool grinder. The steel chips are very different in shape from the other granules, being long, sharp and curly. Photo F represents another engine cleaning, air-blast material, in this case, ground walnut shells. Other shells, kernels and fruit pits crushed to a fine granular material are also used for blast cleaning. These materials are considerably softer than mineral granules and cannot scratch a steel shaft. They have sufficient strength, however, to become embedded in a bearing alloy and scratch it, thereby disturbing a well-fitted bearing.

Metal turnings and chips produced by machining are often too soft to scratch hard shafts, steel gears, etc., but they have ample strength to embed in and damage any bearing surface. Even water can do damage by causing steel to rust. Dehydration of that rust forms an iron oxide, hematite (Fe_2O_3), which is similar to jeweler's rouge, a well-known polishing abrasive. Hematite also can be generated as a product of fretting[3] which is a special form of wear. It can occur when two steel parts rub together, generally with a very limited amplitude, creating its characteristic red coloration at the rubbing surfaces. Once formed, the iron oxide accelerates the attack and eventually produces shallow pits which can act as stress raisers, thereby hastening fatigue failure. These products of fretting are usually very fine, can pass through most screens and filters, and may be circulated into the roll paths of ball and roller bearings and throughout the machine in general, producing wear of a lapping nature. Clearances in rolling contact bearings may increase, even though the surfaces show no gross scratching or obvious damage due to the gentle nature of the lapping action. If trapped in a grease lubricating a ball or roller bearing, hematite can thicken the grease, interfere with lubrication and finally lead to bearing failure.

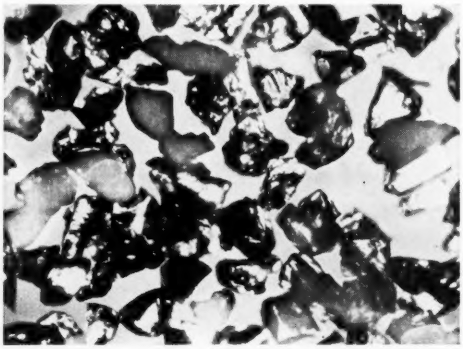
The fact that contaminating solids are entrained in a circulating lubricating system need not necessarily mean that they are potentially damaging or abrasive; it largely depends upon the material, itself. This would include such characteristics as particle size, hardness, shape and strength. Some substances when subjected to the high compressive forces encountered in tight bearing clearances, between gear teeth or in rolling-contact bearings, crush or break down into a fine powder, sufficiently fine that it can pass through the clearance spaces without doing damage. Other granules may soften from frictional heat and melt or plastically flow and so dissipate themselves.

It is obvious that the greater the quantity of grit in a system, the greater will be the opportunity for scratching; however, the converse is not always true. If a single particle having the proper (undesirable) characteristics should become lodged within a bearing clearance, it can possibly score the shaft beyond recovery or initiate a hot-spot leading to final bear-

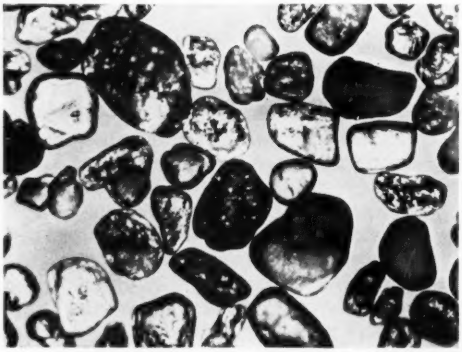
[3]See Lubrication, August 1955, "Fretting and Fretting Corrosion."



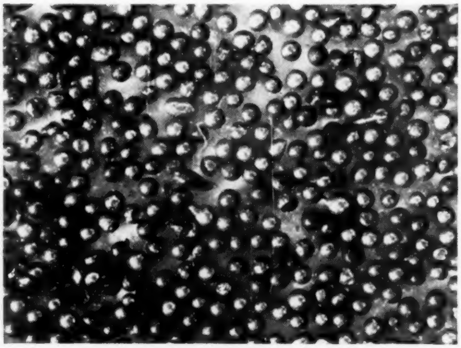
A. Common sand, 20X.



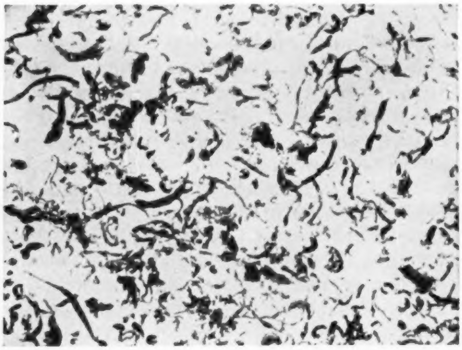
B. Silicon carbide grinding compound, 70X.



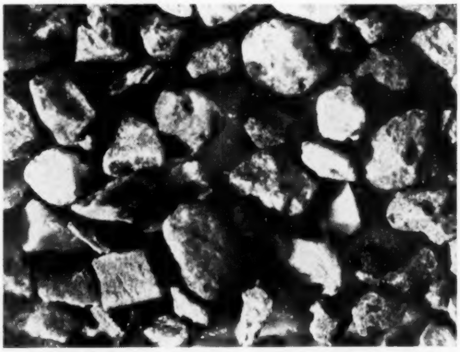
C. Garnet spark plug abrasive cleaner, 40X.



D. Steel grit-blasting material, 10X.



E. Steel grinding chips from tool grinder, 20X.



F. Granulated nut shells used for blast cleaning of engine parts, 10X.

Figure 8 — Materials accessible to machinery in assembly and overhaul shops.

TABLE II

Metric Conversion Units

1 inch	=	25.4 millimeters
1 millimeter	=	0.0394 inches
1 millimeter	=	1000 microns
0.001 inch	=	25.4 microns
1 micron	=	0.0000394 inches
1 micron	=	39.4 micro-inches

ing seizure. From the standpoint of analyses of gross oil samples — as, for instance, drainage from the lube oil sump — the total amount of contaminant in a system may appear insignificantly small (perhaps a few thousandths of one per cent) yet it might be very damaging. Therefore the results of oil analyses are meaningless unless their significance has been established by extensive reference data. A more illuminating analysis might be obtained on the sludge-like material retained in the oil groove of the bearing in question, or from observations of the material trapped on the bearing surface itself. An extension of such an investigational technique may be shown by the micro-hardness measurements which were made on the particles in Figure 2. These are indicated by the elongated diamond-shaped impressions which reveal the granules to have a Knopp hardness of 840, almost the peak hardness available for a high carbon steel. The leaded bronze, in contrast, was considerably softer; it had a Knopp hardness of 110.

Particle Size

Particle size is highly important in any discussion of abrasive wear; yet confusion sometimes exists due to the inter-mixing of English and metric units of length. Bearing clearances and machine fits generally are described in inches and thousandths of an inch; particle diameters, however, are measured in metric units — microns. The accompanying Table II shows the relationship between these two systems of measurement.

It has been found that certain particle diameters are potentially more harmful than others, and this optimum size (if a damaging attribute could be considered as having *optimum* characteristics) varies somewhat with bearing design and running clearance. On the basis of engine tests, it has been found that parts in very close contact such as piston rings in cylinders can become significantly worn by smaller particles than those which show their maximum effect on journal bearings where larger clearances can exist.

Grit in the range of ten microns or less can cause much piston ring wear; however, bearing damage may become most intensive with particles several times that size. In this particular engine example, hardnesses of the mating surfaces may be an added factor; the greater embeddability of the softer bearing surface may protect it from particles which are capable of scoring the harder surface of the cast iron piston ring. Where minimum clearances exist such as in valves, bobbins, actuators, etc., as in aircraft hydraulic systems which consistently are fitted to 0.0002-0.0004 inches, much smaller particles are capable of causing abrasive damage. The hardened steel surfaces are not embeddable; therefore, such applications require very careful handling of hydraulic fluid.

Hardness

Hardness is probably the most important single factor determining whether a particle will scratch or not. The hardness of a material, however, is one of the most elusive properties to define. It cannot be stated in any absolute units such as can electrical resistance or mass but can be defined only by arbitrary standards pertaining to the techniques used to measure it. Hardness, therefore, may be defined as the resistance to indentation, scratching, rebound, abrasion, cutting, etc. As early as 1722, R. A. F. Reaumur attempted to make an orderly investigation of hardness; in 1820 the hardness of minerals was systematized by F. Mohs in what is now known as the Mohs Scale of Hardness, which is given in Table III.

This relationship was based upon the ability of any one mineral being able to scratch the adjacent mineral of lower number; therefore, the "scratch hardness" is, in effect, one way of measuring abrasivity. For example, feldspar (6) will scratch apatite (5) but will not scratch quartz (7). Therefore, feldspar is harder than apatite but not as hard as quartz. By the same means of testing it can be shown that common glass as is used in windows readily scratches apatite, but not feldspar and, therefore, lying between 5 and 6, could be rated as having a Mohs Hardness of 5½.

In the same vein, fully hardened carbon steel

TABLE III

Mohs Scale of Hardness

1. Talc	6. Feldspar
2. Gypsum	7. Quartz
3. Calcite	8. Topaz
4. Fluorite	9. Corundum
5. Apatite	10. Diamond

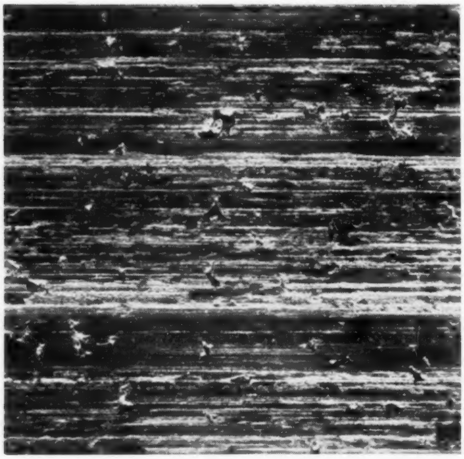


Figure 9 — Surface view of a porous chrome plated cylinder liner scratched by sand which entered through a faulty air cleaner. Magnification 15X.

as used in cutting tools has a Mohs Hardness of about 6½, lying between feldspar and quartz. Silicon carbide, a "synthetic mineral," could be rated at about 9½, being harder than corundum but not as hard as diamond which is the hardest substance known.

As can be seen from this comparative listing, it is not necessary to have an extremely hard substance to create a scratch on steel. Quartz — or common sand which is essentially quartz — is hard enough to scratch the hardest steels and, therefore, could be expected to scratch every component usually encountered in machine tools, engines and other mechanical fabrications. Sand will also scratch chromium which, as electro-deposited, is generally harder than hardened steel. Figure 9 shows the surface of a chrome-plated cylinder liner from a diesel locomotive which had experienced severe dust conditions while operating with a faulty air intake filter.

Another case where metal properties have an important bearing on the final performance is in a situation where a hard particle — either mineral or metal chips — enters the clearance space of a running bearing. If the bearing alloy is sufficiently soft, the foreign chip may embed itself in that alloy and, in effect, be rendered passive. The particles may adhere to the shaft and be dragged around the bearing, producing a scratch in passing. Such an effect can be seen in the lower part of Figure 10 where deep scratches were formed by the particles which finally became embedded at the right-hand end of their travel.

Frequently the impression of a hard solid into the soft bearing matrix will raise a ring of metal around the particle. The ring, by being higher than the original bearing surface, takes up some of the original oil-film clearance space; it might bear upon the shaft and, through wearing, produce a bright shiny band around the particle. The upper portion of Figure 10 shows where two particles had been impressed into the surface, raising a ring of surrounding bearing metal.

The extent to which a soft bearing alloy can be plastically deformed is shown in the cross-sectional view of a scratched surface in Figure 11. This is a "taper section" in which the vertical magnification is ten times the horizontal and reveals how, when a hard particle plowed a groove, it displaced bearing alloy upwards on both sides of the groove, creating two ridges. In this photo, the elevation of the ridges above the normal bearing surface is about two-thirds of the depth of the groove below the surface. The ridge at the right of the groove is flattened at the top, probably polished by contact with the shaft. That polished flat top would correspond to the shiny line frequently seen adjacent to a scratch on a bearing surface.

Physical properties of the bearing metal continue to be important in designs in which the bearing alloy is not thick enough to accommodate the size of the particle, when the bearing composition is hard and resistant or when the journal loads are light. Under such circumstances, the foreign particle may be only partially embedded in the bearing. A portion of the particle will remain projecting above the normal bearing surface in a perfect condition for scratching the shaft. If the scratch forces

Figure 10 — Lead-flashed bearing showing plowed grooves created by hard granules. Note how two embedments at the top of the photo are surrounded by white rings of polished bearing metal. Magnification 8X.

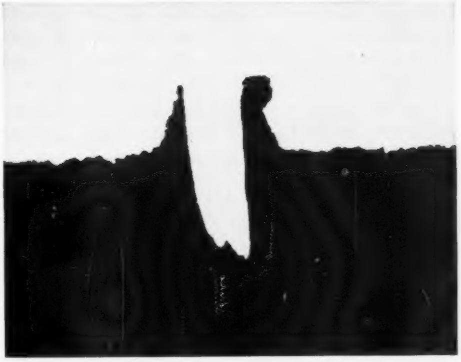


Figure 11 — Taper section of a scratch in a soft bearing alloy showing built-up edges adjacent to the scratch. Magnification: horizontal, 200X; vertical, 2000X.

are great enough, a frictional hot spot will be created which may institute a run-away temperature condition finally resulting in loss of lubrication and seizure. Fine metallic chips produced by machining or grinding operations are particularly troublesome from the standpoint of embedding in bearing alloys due to their frequently curly shape which tightly locks them into the bearing surface. Figure 8 shows metallic particles produced by grinding high speed steel with a silicon carbide wheel. The curly nature is readily apparent. Weld sputter metal is likewise frequently curly, sharp edged and difficult to dislodge once it becomes impressed into the soft bearing surface.

Metallic chips and ferrous weld metal, by being ferro-magnetic (attractable to a magnet), further complicate any attempts at cleanliness, especially at times of inspection-overhaul, when parts have been magnetically tested. Troubles arise when those parts are not completely demagnetized. Even though wiped clean, they will reinfect themselves with magnetic grit if placed on the usually gritty overhaul bench.

The ready availability of quartz (as sand) over the entire earth's surface places a great handicap on every machine operator because constant vigilance is required to guard against the entry of this undesirable material. It must be realized, however, that many other substances equaling or exceeding the hardness of quartz are available. Entry of any of these extraneous materials into mechanical systems must be diligently prevented.

With metals susceptible to scratching or abrasion, physical properties other than hardness play important parts in determining the extent of scratching. Plasticity, ductility, embeddability, etc., greatly influence the final result. Furthermore, properties of the abradant such as compressive strength, crushability, etc., also must be considered.

As an example of an instance where properties of the minerals are dominant, consider silicon carbide having a Mohs Hardness of 9½ with corundum of Mohs 9. Silicon carbide is harder and, potentially should scratch more than corundum; however, silicon carbide is more brittle. If the carbide granules were to gain entry with the lubricant into the mesh of a set of gears, the rolling tooth contacts would produce a crushing action which could fracture the granules, crushing them down to a fine powder more readily than corundum. In so doing, the granules might be crushed sufficiently fine that pronounced scratching would be negligible as compared with that produced by the slightly softer corundum.

Under certain circumstances a bearing surface can be disfigured by a lubricant containing foreign particles which may, in themselves, be quite soft and capable of being crumbled in the fingers. These might be the harder carbonaceous agglomerates such as can develop in the hottest lubricated region of heavy duty engines where "coking" conditions exist; they might be accumulations of lead compounds, residues remaining from the combustion of gasoline containing tetraethyl lead. Blow-by past the piston rings and valve stems allow fuel products to gain access to the lubricating system. Such relatively soft materials generally cause damage only to bearings of soft alloys such as the babbitts that support a pulsating load which produces an ever-changing bearing clearance.

At moments of light load when film thicknesses are at a maximum, the carbonaceous material can slide into the bearing clearance; but, as the full load comes on the journal, the bearing oil clearance is greatly reduced. The solids, only partially plastic and being too hard to be squeezed outwards into a film as thin as the bearing clearance dictates, are temporarily trapped within the bearing while

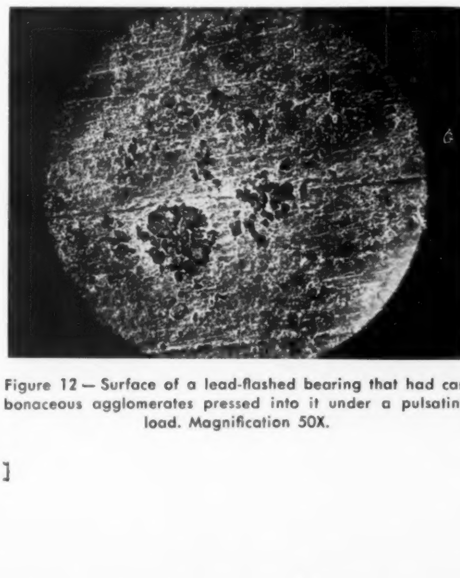


Figure 12 — Surface of a lead-flashed bearing that had carbonaceous agglomerates pressed into it under a pulsating load. Magnification 50X.

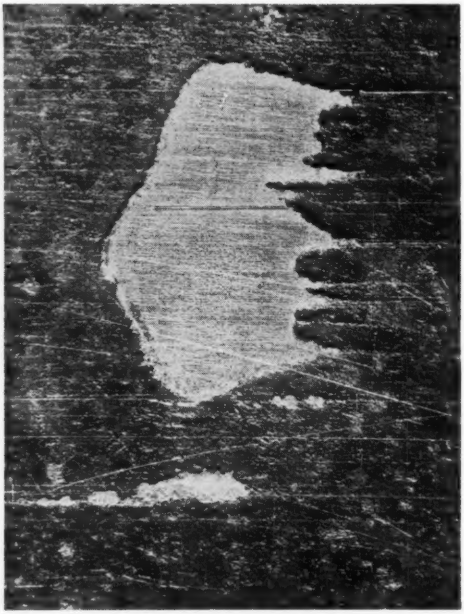


Figure 13 — Surface of aircraft master rod bearing in which the superficial lead layer was eroded away by hydraulic action of circulating solids in the lubricant. Magnification 5X.

they become flattened to thin wafers of deposit. At the same time these deformed discs of carbonaceous material are impressed into the soft bearing surface, creating shallow depressions, some of which may leave raised perimeters similar to those that can be formed by hard granules. Figure 12 shows the surface of a heavy-duty bearing that was coated with a thin layer of lead. Clumps of carbonaceous material circulating in the oil had entered the bearing clearance and became temporarily impressed into the lead. This produced a permanent imprint that distorted and weakened the lead and which upset the smooth flow of oil through the bearing. The final outcome of such damage might be a surface erosion — sometimes called "lead washing" whereby relatively large areas of lead are completely removed by entrained solids as can be seen in Figure 13.

Close examination of a damaged bearing surface will disclose whether the embedded particles were hard or soft. If they were hard, the depressions will simulate the shapes of the particles. Figure 14 shows a bearing surface which had been disfigured by many hard particles passing across it. The journal set up a pulsating load which, once per revolution, squeezed the bearing clearance to a minimum and, at the same time, temporarily impressed the loose solids into the bearing. This produced a series of tracks across the center of the picture. One of the tracks revealed the particle had been triangular in shape. When hard substances are involved, some usually can be found tightly embedded in the bearing alloy. Soft plastic contaminants, however, will produce wide shallow depressions, usually empty of deposits.

ELIMINATION OF ABRASIVES FROM OIL SYSTEMS

The detrimental effects of solid contaminants in a lubricated mechanical element also depend greatly on lubricating system layout and the lubricant in service. These factors, in turn, establish the best methods of eliminating the abrasives.

Piping

The general layout of a lubricating system can affect the *apparent cleanliness* of the circuit. An involved piping system can be extremely difficult to clean completely of all debris once it has become contaminated. Systems which are frequently opened up or reconnected may be particularly troublesome. Such may be the case on engine test stands and other test facilities where machine components are temporarily connected to a common lubrication system only for initial adjustment, running in or otherwise proving the equipment. If just one machine should be dirty before connecting to the common lubricating system, it will contaminate that entire system by the circulation of grit. Subsequent clean machines connected to the same system will, in turn, be infected with grit. Abrasive damage reaching epidemic proportions can be started by one dirty unit.

System Cleaning

When it is not practical to disassemble a lubrication system and clean it, piece by piece, of the offending grit, the only recourse is to attempt to remove it by flushing. Lubricating oil generally circulates through supply pipes under laminar flow

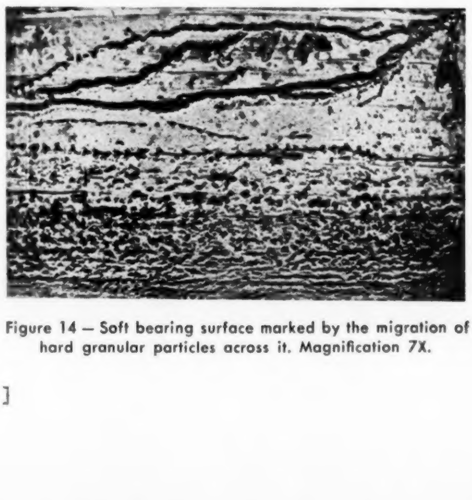


Figure 14 — Soft bearing surface marked by the migration of hard granular particles across it. Magnification 7X.

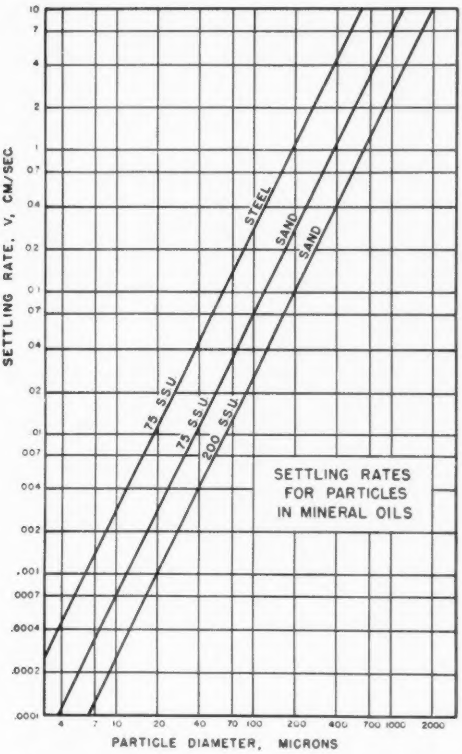


Figure 15 – Settling rates for particles in mineral oils.

conditions which automatically prevents any high surface velocities near the pipe walls. Flushing, therefore, cannot be accomplished adequately by using the lubricant, itself, as the policing medium. Instead, it requires the circulation at high velocities of low viscosity liquids, preferably having solvent and dispersant properties. Furthermore, the state of agitation as produced by engine vibration should be at least as great during flushing as during normal operation. This is necessary to assist in dislodging the more adherent particles particularly where trapped in quiet areas, pockets and corners not easily disturbed by the flushing liquid. Often reverse flushing will remove particles from a system where they might otherwise be trapped in blind spots or other recesses. For use in large circulating oil systems in closed-circuit machines where lubrication performance is highly critical such as in marine and central station steam turbines, specially compounded petroleum-base flushing fluids are available, having sufficient lubricating properties but of low viscosity for high velocity flow; they are suitably compounded to provide optimum cleaning ability and rust protection.

Settling Tanks

In large circulating oil installations there are many instances where settling tanks are used to good advantage to allow solids to drop out of the oil. This is common practice in the metal working industries where large volumes of soluble oil emulsions, cutting oils or cutting-lubricating oils are recirculated continuously and where large concentrations of contaminants must be removed. These contaminants in the forms of metal lathe turnings, chips from milling machines, broaches, etc., are relatively large and, if not picked up by a coarse screen, precipitate very rapidly in a settling tank. Fine granular material, however, such as grinding wheel dust, may not have sufficient time to separate since fine particles precipitate very slowly.

Viscosity of the fluid is the primary characteristic that controls the settling rate of fine solids; the higher the viscosity, the slower the rate of settling. The density of the liquid, although influential, will usually be less important.

Based on Stokes' Law, the plot in Figure 15 has been made for particles of the more common machine contaminants: sand in paraffinic oils of two different viscosities, and steel in the lighter viscosity oil. As a basis for calculation, sand was assumed to have a density of 2.65 and steel 7.8. The lower viscosity (75 Saybolt Universal seconds) is equivalent to a very light spindle or hydraulic

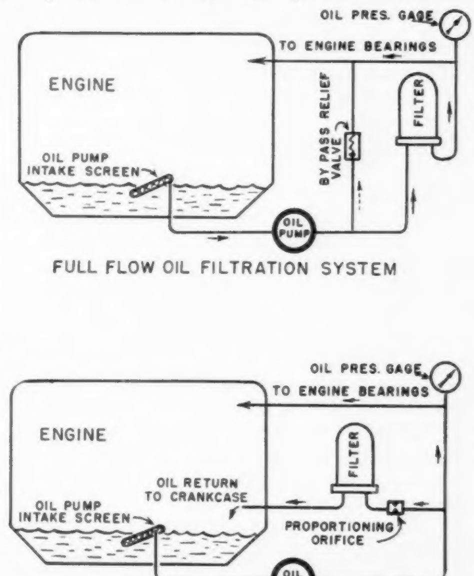


Figure 16 – Typical filter arrangements for oil circulating systems.

oil; this viscosity also approximates an SAE 10-grade motor oil at 180°F. The heavier viscosity (200 S.S.U.) may represent a medium spindle oil or light turbine oil near room temperature; it would also approximate a heavy aircraft engine oil (120-grade) at 180°F.

From this plot it can be seen that materials which are small enough to enter most bearing clearances have very low settling rates. For instance, grains of sand 100 microns in diameter (about 0.004 in.) in the low viscosity oil precipitate at a rate of only 0.07 cm/sec.; almost seven minutes for one foot drop. Particles one-tenth that diameter (10 microns) which have been known to damage precision lapped surfaces or mar the mirror-finish of bright rolled sheet stock would settle at a rate one hundred times slower. It is apparent, therefore, that clarification by settling (or centrifuging) cannot be applied to very fine particles, even though such a method is feasible for large chips. The best known way is by the use of filters.

Filters[4]

It is common practice, especially in automotive engine installations, to have the suction side of the oil circulating pump fitted with a wire screen of 16-50 mesh size; many machine tools are equipped with finer screens — up to 200 mesh. Such screens protect the pump from physical damage by preventing the entry of loose metal parts such as cotter pins, nuts, lathe turnings, etc. Screens, however, are sometimes erroneously regarded as protecting the bearings from wear particles; that is not the case. A 16-mesh screen will pass particles of about 0.040-inch diameter (1000 microns); a 100-mesh screen passes those with diameters 0.006 inches (145 microns). Therefore, to safeguard bearings whose minimum film thickness may be 0.0002-0.0004 inches, protection down to 5-10 microns is required, a job done most efficiently by absorbent filters.

Filters of fine pore size offer considerable restriction to flow due to the small clearances involved. Frequently the addition of a single full-flow filter to an already existing circulating system cannot be tolerated due to the pressure drop created by that filter (see Figure 16). Excessive pressure drop can be reduced or the capacity increased by multi-element filters, which in some industrial installations may have several dozen elements in one filter system.

Full-flow filter arrangements generally are regarded as being most satisfactory from the standpoint of keeping an oil clean. High oil flow rates, however, may impose demands of size and weight, that make their use prohibitive as, for example, in an installation on an aircraft engine where a high viscosity oil may circulate at a rate of about 50 gallons per minute. Full-Flow filters require competent maintenance, especially if there should be a chance for the elements becoming clogged, restricting the oil flow. This can starve the bearings unless a by-pass relief valve can divert the unfiltered oil around the filter to the bearing.

As a compromise, by-pass filtration has long been quite effective (Figure 16). It allows full oil flow to the bearings; however, as filtration is taken care of in a branch line, the main supply from the oil sump goes unfiltered directly to the bearings, whereas the cleanest, filtered oil returns to the sump. By-pass filters can have a very tight construction, producing a very clean oil; however, as the main flow to the bearing is not filtered, it is quite possible for particles to circulate for a long time before being diverted into the filter side-stream. The by-pass arrangement has the advantage that, should the filter become plugged with excessive amounts of contaminants, the flow rate to the bearings will not be impaired.

Filters are most effective when they are in continuous use. When they are used intermittently or as batch treatment, the oil may become excessively loaded with contaminants before the filter can reduce them to an acceptable level.

[4]For a more complete treatment see Lubrication, March 1954 "Filters and Purifiers for Oil Circulating Systems."

CONCLUSIONS

It is an old maxim that "there is no substitute for clean oil." This is especially true when one appreciates the damage that can occur from oil containing abrasive materials. Modern, heavy duty bearings are more susceptible to damage than those in older applications because of high unit loads, thin oil films and harder, less embeddable bearing surfaces. Abrasive ~~damage rarely heals~~ itself; usually it is cumulative and tends to encourage other malfunctions such as high oil consumption, loss of oil pressure, bearings overheating, etc. Therefore, greater diligence is required today to guard against grit. Oil drains, alone, cannot control the whole situation; it goes back to the original condition prior to the time of the initial oil charging.

There are potentially two major sources of contamination in most mechanical equipment: (1), dirt built in during assembly or overhaul, resulting from incomplete cleaning, poor shop practice, house cleaning, etc., and (2), airborne dust entering during machine operation. Keeping such debris out of oil systems, therefore, is a never-ending job throughout the life of a machine. Tight systems with continuous maintenance are the true safeguards for eliminating abrasive wear.

Remember — oil does not scratch! So keep out the abrasives and let the oil do its job properly.

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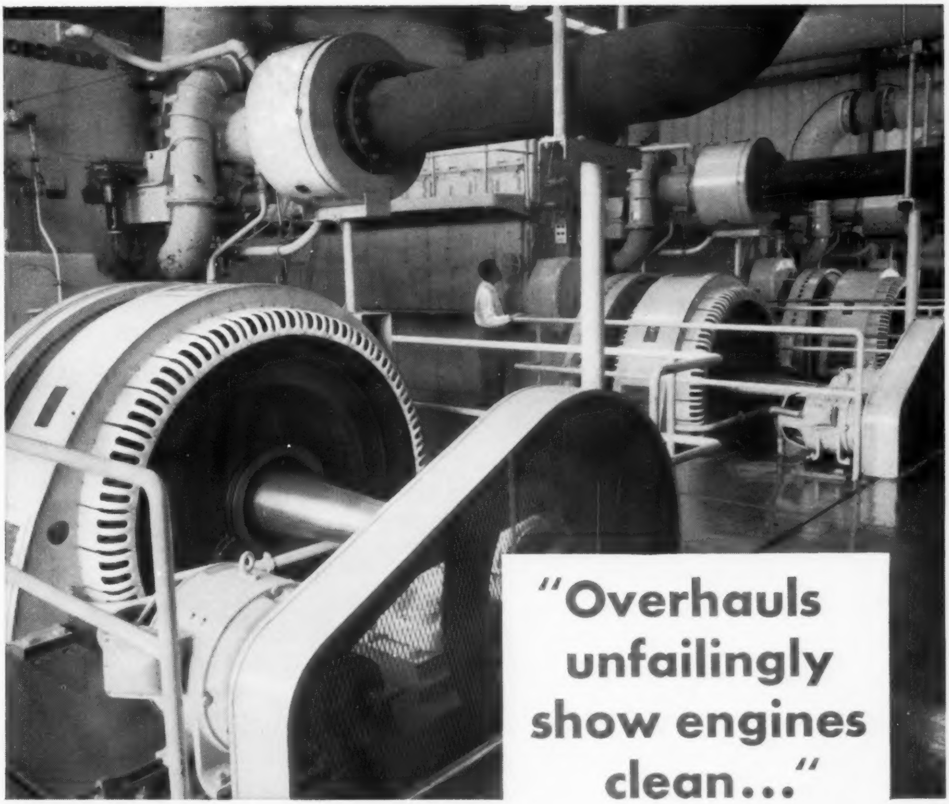

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